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# Air Conditioning System

## *Introduction*

The present invention relates to an air conditioning system, in particular to an air conditioning system having carbon dioxide as refrigerant, particularly for use in a motor vehicle.

## *State of the Art*

As a result of the need to reduce the energy consumption arising from the use of automotive air conditioning systems, electronically controlled compressors are being increasingly applied. This permits external control, which can be used to advantage in a number of different ways. The most valuable in energy efficiency terms is the management of the evaporation temperature to reduce the necessary amount of reheat to a minimum.

Automotive air conditioning systems with carbon dioxide as refrigerant usually have an electronically controlled compressor, but also require an extra degree of flexibility in the form of an electronically controlled expansion valve. The result of having two control elements means that different combinations of settings of the two devices can yield the same cooling performance. However these different combinations will have different energy efficiencies. A control system can be used to control the system to the combination, which yields the highest energy efficiency.

The standard solution to this problem is to look for optimum COP (coefficient of performance) for fixed compressor displacement and is based on the recognition that for any given operating point the required head pressure for optimum efficiency is a simple function of the refrigerant temperature at the gas cooler outlet. The control problem reduces to one of establishing the relationship so that for any measured gas cooler outlet temperature the system knows what head pressure to control to.

An other proposed solution to the problem is given in WO 00/06821. In this patent application, it is disclosed that one should identify the optimum COP for

fixed system cooling capacity and not for fixed displacement. WO 00/06821 defines an operating band for all the COP optima and claims that one only needs to control within this band to achieve optimum efficiency. The operating band is determined by taking into account the refrigerant temperature and pressure on the expansion valve inlet side. Experimental data however indicates that to it is insufficient to lie within the operating band defined in WO 00/06821 but that each operating point has its own tolerance band to ensure control is near enough to the optimum. Thus simply being within the band does not mean that optimum COP will be achieved in any particular case. Thus, optimum efficiency is not achieved at all operating points.

### *Object of the invention*

The object of the present invention is to provide an improved air conditioning system that operates at optimum efficiency in all operating ranges. This object is achieved by an air conditioning system as claimed in claim 1.

### *General description of the invention*

In order to overcome the abovementioned problems, the present invention proposes an air conditioning system, in particular an air conditioning system having carbon dioxide as refrigerant, particularly for use in a motor vehicle. The air conditioning system comprises a compressor, the compressor having a compressor capacity control element, a gas cooler, an expansion valve and an evaporator arranged in series and forming a closed circuit for the refrigerant. The air conditioning system further comprises a controller for controlling the compressor capacity control element and the expansion valve so as to regulate an expansion valve inlet pressure. The controller regulates the expansion valve inlet pressure by controlling the compressor capacity control element so as to align evaporator air off temperature with a set point; by monitoring expansion valve inlet temperature; by determining a required expansion valve inlet pressure corresponding to the monitored expansion valve inlet temperature by means of a control algorithm; and by adjusting the expansion valve and the

compressor capacity control element together along an iso-capacity curve to the required expansion valve inlet pressure.

By regulating the expansion valve inlet pressure by controlling the compressor capacity control element so as to align evaporator air off temperature with a set point, the desired cooling capacity of the system is set. By then adjusting the expansion valve and the compressor capacity control element together along an iso-capacity curve to the required expansion valve inlet pressure, the optimum COP can be achieved while maintaining that particular cooling capacity. The optimum COP is achieved in all operating conditions due to the use of the algorithm for determining the required expansion valve inlet pressure.

Preferably, the control algorithm comprises one or more control parameters chosen from the list comprising front end air flow; gas cooler air inlet temperature; evaporator air flow; evaporator air inlet temperature; evaporator air inlet humidity; compressor speed; and the set point. The inventor has recognised that these control parameters influence the efficiency of the system and that it is beneficial to take them into account in the control algorithm for determining the required expansion valve inlet pressure. Optimum COP can thereby be guaranteed in all operating conditions.

The above control parameters can be set, estimated or measured, e.g. directly measured by means of sensors. The front end air flow can e.g. be estimated as a function of vehicle speed and fan speed. The gas cooler air inlet temperature can e.g. be estimated as a function of vehicle speed and ambient temperature. The evaporator air flow can e.g. be estimated as a function of blower speed, air temperature door setting, air distribution mode and air recirculation mode, wherein the air temperature door is used to mix heated air with cooled air so as to obtain the desired air temperature before distributing it to the passenger compartment, the air distribution mode is used to direct the conditioned air to different parts of the passenger compartments, such as e.g. windscreen, face or feet, and the air recirculation mode is used to either draw air from the passenger compartment or from the outside of the vehicle. The

evaporator air inlet temperature can e.g. be calculated as a function of cabin temperature, ambient temperature and air recirculation mode.

According to one embodiment, the compressor is a variable stroke compressor and the compressor capacity control element is a compressor control valve for regulating the stroke of compressor pistons. Such a variable stroke compressor generally comprises a swash plate, swash ring or wobble plate for adjusting the stroke of the compressor pistons depending on the pressure acting on the front and the back of the pistons. The compressor control valve is used to regulate the pressure acting on the back of the pistons with respect to the pressure acting on the front of the pistons, thereby regulating the stroke of the pistons and hence the capacity of the compressor.

According to another embodiment, the compressor is a variable speed compressor and the compressor capacity control element is a variable speed electric drive for regulating the speed of the compressor. Such compressors have fixed displacement and use an electric drive to adjust the speed of the compressor and thereby also the compressor capacity.

Advantageously, an internal heat exchanger is arranged between the gas cooler and the expansion valve. The internal heat exchanger removes heat from a region between the gas cooler and the expansion device and transfers it to a region between the evaporator and the compressor. Due to the internal heat exchanger, more heat can be dissipated in the evaporator, thereby improving the performance and efficiency of the system.

It will be appreciated that, if no internal heat exchanger is present, the gas cooler outlet pressure, resp. temperature, is the same as the expansion valve inlet pressure, resp. temperature. In this case, the expansion valve inlet pressure, resp. temperature, can be measured anywhere between the gas cooler and the expansion valve. However, if an internal heat exchanger is present, there is a temperature difference and a small pressure difference between the refrigerant at the gas cooler outlet and the refrigerant at the expansion valve inlet. The pressure and temperature should therefore be measured at expansion valve inlet.

*Detailed description with respect to the figures*

The present invention will be more apparent from the following description of a not limiting embodiment with reference to the attached drawing, wherein Fig.1 shows a schematic view of an air conditioning system according to the invention.

Fig.1 shows an air conditioning system 10, which can e.g. be installed in an automotive vehicle. Such an air conditioning system 10 comprises a compressor 12, a gas cooler 14, an expansion valve 16 and an evaporator 18. The different elements 12, 14, 16, 18 are connected in series by fluid pipes and form a closed circuit wherein a refrigerant, e.g. $CO_2$, can circulate. The refrigerant exits a discharge port 20 of the compressor 12 under high pressure and is fed to the gas cooler 14, where it is cooled. The refrigerant then flows to the expansion valve 16, where it expands and drops in pressure. From the expansion valve 16, the refrigerant is led to the evaporator 18, where it evaporates. The refrigerant is then led back to a suction port 22 of the compressor 12. An internal heat exchanger 24 can be fluidly arranged between an outlet port 26 of the gas cooler 14 and an inlet port 28 of the expansion valve 16, and between an outlet port 30 of the evaporator 18 and the suction port 22 of the compressor 12. Such an internal heat exchanger 24, sometimes also referred to as superheater, comprises a high-pressure internal heat exchanger inlet 32 for receiving refrigerant from the gas cooler 14; a high-pressure internal heat exchanger outlet 34 for delivering refrigerant to the expansion valve 16; a low-pressure internal heat exchanger inlet 36 for receiving refrigerant from the evaporator 18; and a low-pressure internal heat exchanger outlet 38 for delivering refrigerant to the compressor 12. The internal heat exchanger 24 removes heat from a region between the gas cooler 14 and the expansion valve 16 and transfers it to a region between the evaporator 18 and the compressor 12. More heat can be dissipated in the evaporator 18, thereby improving the cooling capacity and efficiency of the air conditioning system 10. Furthermore, an accumulator/dehydrator device 40 can be fluidly arranged between the outlet port 30 of the evaporator 18 and the suction port 22 of the compressor 12,

preferably upstream of the internal heat exchanger 24. The accumulator/dehydrator device 40 prevents liquid refrigerant from reaching the compressor 12 by storing excess liquid refrigerant coming from the evaporator 18. The accumulator/dehydrator device 40 also removes debris and moisture from the system.

A controller 42 is provided for controlling the performance of the air conditioning system 10. The controller 42 controls the capacity of the compressor 12 by acting on a compressor capacity control element (not shown) of the compressor 12. The compressor 12 can be a variable stroke compressor wherein the compressor capacity control element is a compressor control valve. The controller 42 acts on the compressor control valve so as to increase or decrease the pressure of the refrigerant acting on the back of the pistons with respect to the pressure of the refrigerant acting on the front of the pistons, thereby adjusting the stroke of the pistons and the capacity of the compressor 12. By changing the capacity of the compressor 12, the cooling capacity of the air conditioning system 10 can be set. Hence, the controller 42 is designed to regulate the compressor capacity control element evaporator pressure so that evaporator air off temperature is aligned with a set point, i.e. so that the desired cooling capacity is obtained. In order to optimise the COP of the air conditioning system, the controller 42 monitors expansion valve inlet temperature; determines a required expansion valve inlet pressure corresponding to the monitored expansion valve inlet temperature by means of a control algorithm and then adjusts the expansion valve 16 and the compressor capacity control element together along an iso-capacity curve to obtain the required expansion valve inlet pressure. The optimum COP can thereby be achieved while maintaining that particular cooling capacity.

The controller 42 uses control parameters, such as front end air flow, gas cooler air inlet temperature, evaporator air flow; evaporator air inlet temperature, evaporator air inlet humidity, compressor speed and the set point, in the control algorithm to determine the required expansion valve inlet pressure. The inventor has recognised that, as head pressure is changed, by whatever means, there are associated changes in just about every other

operating parameter within the refrigerant loop and significant deviation from the idealisation is seen. For example, as the expansion valve is closed to increase head pressure, mass flow rate changes, heat exchanger effectiveness and thus fluid outlet conditions adjust and isentropic efficiency of the compressor changes as pressure ratio changes. The gas cooler outlet temperature and evaporator pressure are therefore not sufficient to determine the required expansion valve inlet pressure since some or all of the above control parameters influence the efficiency of the system. It is thus beneficial to take the above-mentioned control parameters into account in the control algorithm for determining the required expansion valve inlet pressure. Optimum COP can then be guaranteed in all operating conditions.

The inventor has also recognised that each operating point optimum has its own tolerance band. It will be appreciated that including every single control parameter in the algorithm can lead to the need for quite substantial computing power, which is not necessarily available in a vehicle. By using only some of the control parameters, the needed computing power can be reduced, while at the same time, the accuracy of the COP point is reduced. A compromise can hence be made between the needed computing power and the accuracy with which the required expansion valve inlet pressure can be determined for optimum COP.

*Reference Signs*

10 air conditioning system

12 compressor

14 gas cooler

16 expansion valve

18 evaporator

20 discharge port of compressor

22 suction port of compressor

24 internal heat exchanger

26 outlet port of gas cooler

28 inlet port of expansion valve

30 outlet port of evaporator

32 high-pressure internal heat exchanger inlet

34 high-pressure internal heat exchanger outlet

36 low-pressure internal heat exchanger inlet

38 low-pressure internal heat exchanger outlet

40 accumulator/dehydrator device

42 controller